AD-A080 871 FOREST PRODUCTS LAB MADISON WI F/G 13/13
DESIGN, FABRICATION, TESTING, AND INSTALLATION OF A PRESS-LAM B--ETC(U)
1979 J A YOUNGQUIST, D S GROMALA
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**Forest
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Laboratory**

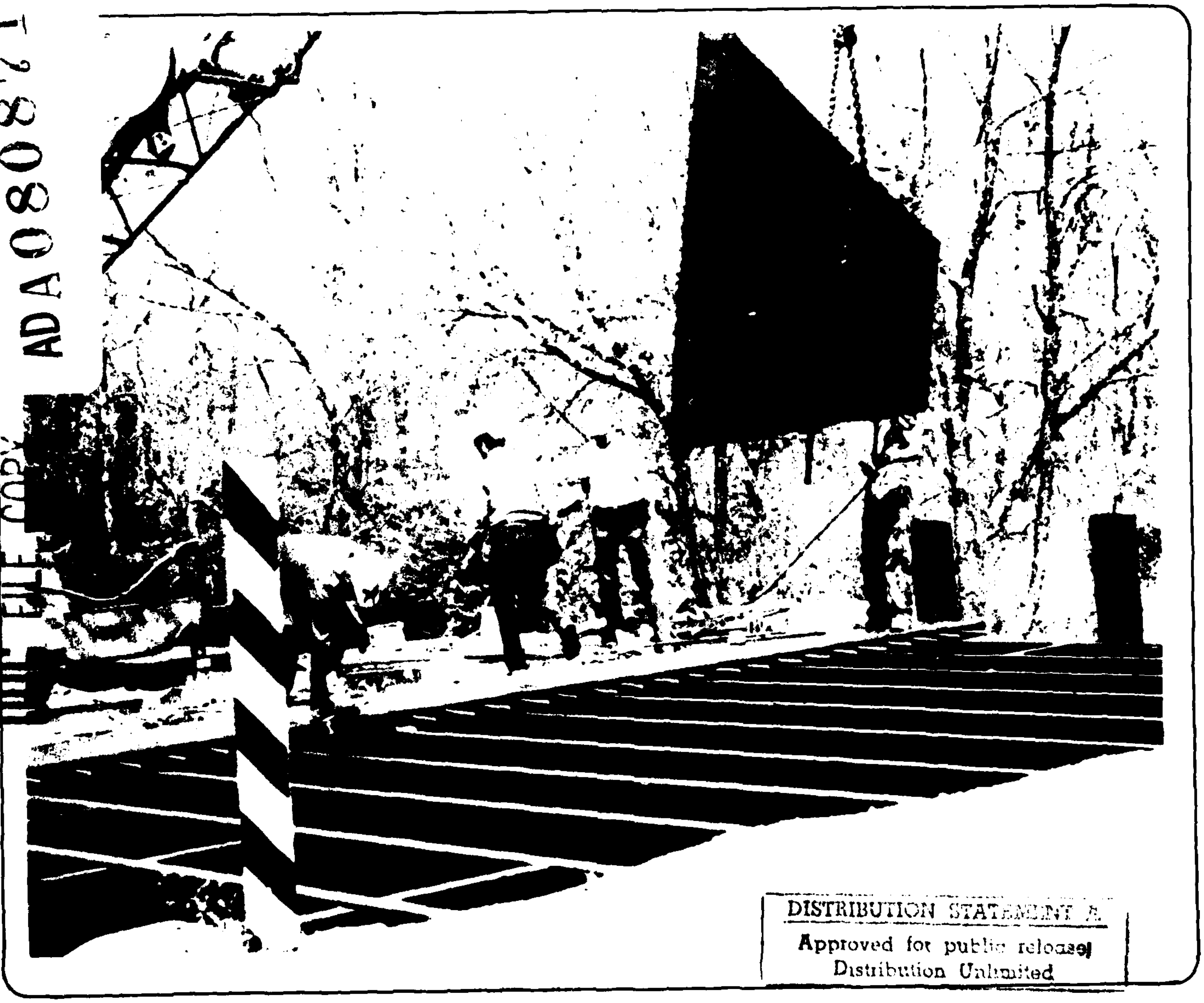
Research
Paper
FPL 332
1979

# Design, Fabrication, Testing, and Installation of a Press-Lam Bridge



(12)







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## Abstract

Parallel laminated veneer (PLV) products are manufactured by adhesive bonding of rotary-peeled veneer. It has been estimated that a production line PLV process could convert green logs into a finished structural laminate in less than an hour.

Press-Lam, a PLV product under investigation at the U.S. Forest Products Laboratory, has exhibited decreases in variability of mechanical properties and increases in chemical preservative penetration and retention when compared to solid-sawn lumber.

A prototype highway bridge constructed entirely of Press-Lam has been erected by the Virginia Department of Highways and Transportation. This bridge was field tested to its AASHTO HS-20 design load. Preliminary allowable stresses were determined by data obtained from destructive laboratory tests on 18 full-scale stringers and 6 sections of decking made from Douglas-fir Press-Lam.

In the face of dwindling supplies of large structural timbers, PLV products are attractive alternatives for exposed structural applications.

## Acknowledgments

The assistance of Roger Tuomi, Research Engineer at the Forest Products Laboratory, in providing advice in testing the bridge components and erecting the bridge is much appreciated. The authors also wish to thank technicians John Hillis, Bill Kreul, Tedd Mianowski and Bob Patzer, and Romaine Klassy of the Laboratory for completing the necessary material fabrication jobs ahead of schedule.

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## The Authors

The authors of this paper and their respective roles in this research were:

J. A. Youngquist, Chemical Engineer, Team Leader, to coordinate overall project;

D. S. Gromala, Engineer, to determine material properties and bridge design;

R. W. Jokerst, Forest Products Research Technologist, to oversee adhesive and bond quality and laminating;

R. C. Moody, Engineer, to determine laminated material strength properties and structural performance;

J. L. Tschernitz, Chemical Engineer, to develop drying and processing concepts and oversee fabrication of components.

## Foreword

This publication summarizes the work of a team of FPL research scientists who studied both the processing and the physical and mechanical properties of large PLV panels and structural members, which were assembled into a demonstration highway bridge structure. The bridge work described here covers one of four FPL chosen demonstration uses of PLV for structural and/or specialty products. Other demonstration uses include railroad ties, electrical distribution crossarms, and basement beams.

This project involved close cooperation among the State of Virginia, the U.S. Department of Agriculture's Forest Service, and the U.S. Department of Transportation's Federal Highway Administration. The principal individuals involved in this project in addition to the authors are:

State of Virginia
  Department of Highways and Transportation, Mr. F. G. Sutherland, State Bridge Engineer.
    Virginia Highway and Transportation Research Council, H. E. Brown, Assistant Head, and M. M. Sprinkel, Research Engineer.

U.S. Department of Agriculture, Forest Service
  National Forest System
    Engineering Staff, M. R. Howlett, Director, and L. Bruesch, Chief Bridge Engineer.
    George Washington National Forest, G. Smith, Forest Supervisor.
    Mount Hood National Forest, W. Mallory, Forest Supervisor (since retired)
  Pacific Northwest Forest and Range Experiment Station, R. O. Woodfin, Project Leader.

U.S. Department of Transportation, Federal Highway Administration, Office of Development, A. Lizzio, Engineer.

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Forest Products Laboratory[1]
Forest Service
U.S. Department of Agriculture

# Design, Fabrication, Testing, and Installation of a Press-Lam Bridge.

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By
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## Introduction

The concept of parallel laminating veneer into thick sheets of any width or length is being examined as an alternative to solid-sawn timber or glulam for structural-sized or specialty-type members. Research work on this concept of improved resource utilization has been going on for several years, and has been conducted by researchers in the USDA Forest Service (13,23,24)[2] and the Canadian Forestry Service (6), and by the forest products industry (21). Investigations by these research groups have resulted in a number of concepts for producing parallel-laminated material. Process variables that have been investigated include veneer thicknesses, adhesive types, drying methods, and laminating techniques.

Research in the last 10 years has shown that laminated veneer products offer advantages of increased product yield and improved product performance when compared to conventional lumber. Because of the dispersion of wood defects inherent in the laminating process, lower limits of bending strength can be increased, and stiffness can be more uniform. Additionally, research at the Forest Products Laboratory (FPL) (29) has shown that preservative treatment of a difficult-to-treat species is improved considerably when laminations are peeled rather than sawn. In other words, a product can be made which can reliably meet a given set of end-use requirements.

Research teams at FPL have examined the basic physical and mechanical properties of parallel laminated veneer (PLV), and evaluated potential markets for products assembled using this technology. This product, called Press-Lam, is made using a veneer lathe to cut the wood, a heated press to dry it, and adhesive and a cold press to produce a continuous sheet of wood with thickness, width, and length restricted only by the size of production line equipment. This sheet can then be ripped and cross-cut to the desired end-product dimensions. The overall process, as used to produce the bridge components for this study, is shown in figure 1. The finished product differs from plywood in that all veneers are placed with the grain parallel to each other and that thick veneers (up to ½ in.) are used. The name Press-Lam was coined to reflect the use of presses to dry the veneer and to apply pressure during lamination.

A bridge demonstration structure was chosen because Press-Lam might be well suited to fill a current national need. The U.S. Department of Transportation, Federal Highway Administration, has estimated that over 100,000 small-span bridges in the United States are in need of repair or replacement. The estimated cost of upgrading these bridges ranges as high as $23 billion (7). Many of these bridges could be replaced with timber bridges which exhibit advantages of long life, competitive cost, ease of installation, and a visual compatibility with natural settings.

These Federal Highway Administration statistics, coupled with the fact that timber bridges have played an important role in Forest Service bridge history, made the choice of a demonstration structure an easy one.

A cooperative project was organized for the design, manufacture, installation, and in-service evaluation of a bridge to be made entirely from PLV components. A cooperative agreement with the following agencies was developed to accomplish this task:

- State of Virginia Department of Highways and Transportation (VDH&T)
  - Provided the bridge site in the George Washington National Forest.
  - Approved the final bridge design.
  - Erected the finished bridge structure.
  - Will be monitoring the bridge performance over the next 5 years.
- U.S. Department of Agriculture, Forest Service
  - National Forest System
    - Engineering Office—Provided funds for procurement of the materials for the bridge components. Provided overall project management and guidance.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Underlined numbers in parentheses refer to Literature Cited near end of report.

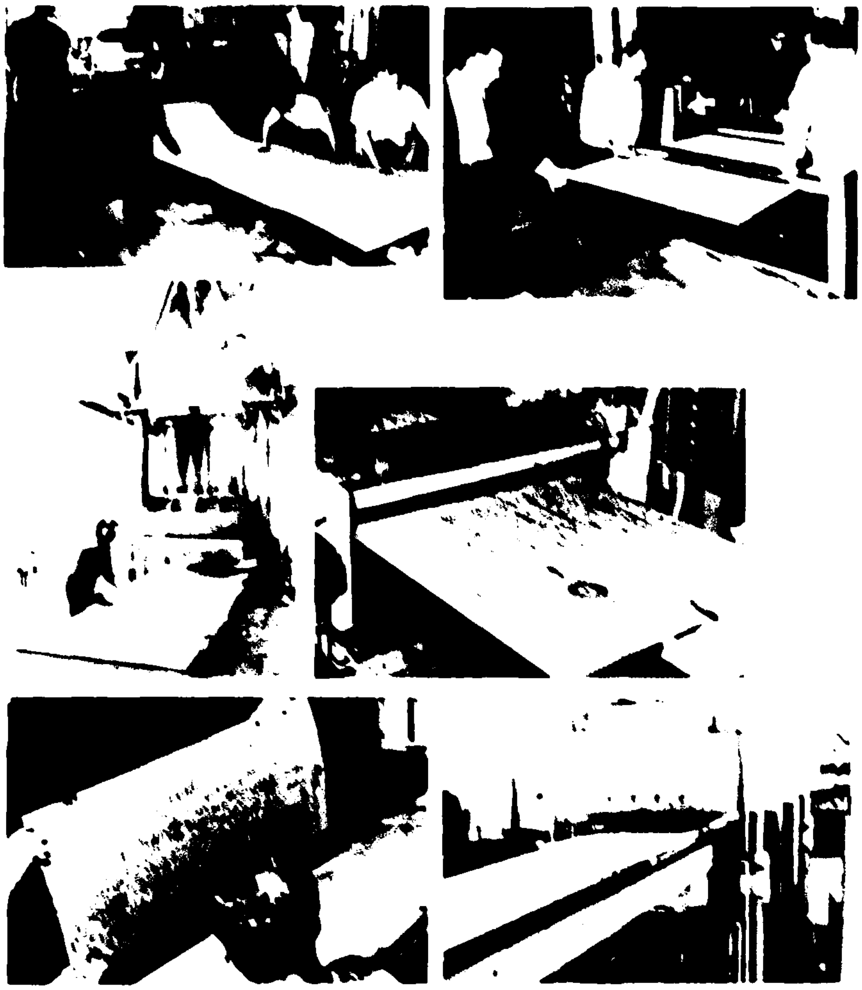

Figure 1.—Schematic of the process used at FPL to produce bridge components.
Upper left: Producing veneer.
Upper right: Clipping veneer.
Center left: Press drying veneer.
Center right: Applying adhesive to hot veneer.
Lower left: Layup of dimension stock.
Lower right: Laminating dimension material.
[illegible]

The bridge is located on State Secondary Route 610, in the George Washington National Forest, about 100 miles west of Washington, D.C., near Orkney Springs in Shenandoah County, Va. The previous bridge was an 18-foot, single-lane, simple span over Stony Creek, which needed to be upgraded and widened to two-lane standards.

The purpose of this report is to describe the manufacture of the bridge components, the evaluation of component performance, the procedures and rationale used in the bridge design, and the bridge installation and proofloading.

Plans call for the Virginia Highway and Transportation Research Council to oversee a 5-year bridge performance evaluation program. Because the demonstration structure is expected to exhibit attractive alternatives for the Nation's bridge engineers, the Federal Highway Administration is cooperating in the preparation and distribution of a 16-millimeter, color, sound movie of all the facets of this project. This movie, which is available for short-term loan to interested parties, can be obtained by contacting either the U.S. Department of Agriculture, Forest Products Laboratory, Madison, Wis., or the U.S. Department of Transportation, Federal Highway Administration, Office of Development, Washington, D.C.

Mount Hood National Forest
Provided Douglas-fir logs for fabrication into bridge stringers and deck panels.
George Washington National Forest
Provided red oak logs for fabrication into curbs, rails, and guard posts.
Forest Products Laboratory
Developed the Press-Lam concept.
Developed a preliminary bridge design.
Fabricated or coordinated the fabrication of all the bridge components.
Determined the structural properties of the primary bridge components.
U.S. Department of Transportation, Federal Highway Administration
Is assisting in the production of a technical movie documenting this project.
Will be involved in technology transfer activities, communicating with potential users and/or producers of PLV for structural applications in small span bridges.

## Materials

### Raw Material Requirements

The stringers and deck sections of this bridge were manufactured from Coast-type Douglas-fir, grade 1 or 2 saw logs (14). This species was chosen to demonstrate that Coast-type Douglas-fir, which is sometimes difficult to treat, can be more thoroughly treated in the form of laminated veneer (22).

Approximately 31,000 board feet (Scribner C log scale) of Douglas-fir storm-salvaged material was obtained from the Mount Hood National Forest in Oregon for the stringers and deck panels. Approximately 2,500 board feet (Scribner C log scale) of construction-grade red oak (22), obtained from the George Washington National Forest in Virginia, was used for the curbs, rails, and posts.

The preliminary bridge design, based upon assumed material properties from previous FPL research (23,24), called for longitudinal stringers 4½ inches wide by 20 inches deep, spaced 2 feet apart, and a transverse deck approximately 3½ inches thick. Enough Press-Lam dimension material was manufactured for both the finished structure and for the test program. The tests were used to verify the assumed design properties for the primary structural members.

**Raw Material Characterization**

A total of 23 Douglas-fir logs (up to 32 ft long and about 24 in. diameter) were cut into 4 to 7 bolts (52 in. long) per log. A 2- to 3-inch-thick disk was removed near the middle of each log and used to determine diameter, moisture content, specific gravity, and ring count (table 1).

In Douglas-fir logs of these diameters the width of sapwood is typically small, 1 to 3 inches. The moisture content (ovendry basis) of sapwood was as high as 140 percent, whereas heartwood was consistently between 30 and 35 percent, which is typical for fresh logs. Some of the veneer contained both sapwood and heartwood. Veneers having greater than 25 percent sapwood were classified and dried as sapwood veneer. The amount of the veneer classified as sapwood varied from 10 to 30 percent in the bolts, averaging 18 percent (table 1). Because the red oak logs were used in secondary structural components, detailed specific gravity and ring count measurements were not determined.

Following peeling and clipping, all of the veneer was visually graded into five different classes (table 2) which closely paralleled common veneer grades (33). The total number of knots in each class was also recorded. It should be pointed out that veneer is commonly graded as full-size sheets (48 x 96 in.) compared to 21- by 48-inch sheets in this case. This fact tends to shift the apparent veneer quality in this study to higher grades.

**Veneer Cutting**

The Douglas-fir and red oak logs were stored outside, and were sprayed with water anytime the temperature exceeded 40° F. All logs were cut into 52-inch-long bolts with a chain saw, heated in water prior to debarking, and peeled on a 4-foot lathe. The 151 Douglas-fir bolts were heated to 140° F for 92 hours prior to peeling. For the 32 red oak bolts, a double heating schedule, 120° F for 24 hours and 160° F for approximately 36 hours, was used to minimize thermal end checking. All bolts were chucked on their geometric centers. The Douglas-fir bolts were peeled to a thickness of 0.420 inches, and the red oak bolts were peeled to 0.386 inches. Eight-inch-diameter chucks were used for peeling to core diameters of 9.5 inches.

Of the Douglas-fir bolts processed, only four split-outs occurred at peeled diameters ranging from 10¼ to 16½ inches. No spin-out or split-out problems were encountered with the red oak bolts.

The Douglas-fir veneer was clipped to a 21½-inch width. The Douglas-fir sapwood was separated from the heartwood to accommodate different drying schedules. The red oak veneer was clipped to an 18-inch width. All green material was then put on pallets and wrapped in polyethylene. If veneer was to be stored for more than 4 days prior to drying, it was cooled to 35° F or lower to prevent surface mold.

**Table 1.—Physical properties of logs determined from disks cut near log middle**

| | Log diameter | | Average specific gravity[1] | Ring count | | Veneer sapwood[3] |
|---|---|---|---|---|---|---|
| | Major | Minor | | Log average[2] (full radius) | Within log (1 inch of radius) | |
| | In | | | Rings in | | Pct |
| Maximum | 31.8 | 30.0 | 0.53 | 40.3 | 78 | 29.5 |
| Minimum | 20.3 | 19.0 | .39 | 19.0 | 4 | 10.4 |
| Average | 25.8 | 24.1 | .46 | [4]27.4 | | 18.1 |

[1] Ovendry weight and green volume basis.
[2] Log averages are for the full radius and within log averages are for a 1 inch section of radius.
[3] Veneer containing 25 percent or more sapwood was classified as sapwood.
[4] Weighted area average.

**Table 2.—Percentage of various veneer grades**

| Veneer grade | Knot size class | Test material[1] | Bridge components | All veneers |
|---|---|---|---|---|
| | In | Pct | Pct | Pct |
| A | clear | 20.5 | 14.1 | 17.5 |
| B | < 1 | 45.9 | 49.5 | 44.0 |
| C | 1 to 1½ | 27.8 | 33.3 | 33.3 |
| D | 1½ to 3 | 5.9 | .9 | 4.7 |
| E | > 3 | .06 | 2.1 | .5 |

[1] Test material 1,196 veneers, bridge components 2,221 veneers, total veneers graded 5,476.

**Veneer Drying**

The correlation of press-drying rates of various veneers as a function of temperature, thickness, and pressure has been reported for red oak (9,30), and Douglas-fir (23). These press-drying studies were conducted on 3- by 3-, 4- by 4-, and 2- by 8-foot presses, all fitted with ventilated cauls. Because of the amount of material to be dried for the Press-Lam bridge project, a 4- by 20-foot press was used. A used 60-mesh, bronze Fourdrinier screen was tested and found suitable for drying the Douglas-fir veneer. The screen provided sufficient venting of water vapor in both sapwood and heartwood such that no "blowups" of veneer were observed for the drying temperatures used. For this sample of Douglas-fir, the drying rates with the screen and with conventional ventilated cauls were observed to be the same.

The ideal Press-Lam processing concept calls for use of residual heat from drying to cure the adhesive. This scheme was not possible because the press used for drying was in a building separate from the laminating

equipment. Instead, the veneer was dried in the 4 by 20 press (10 per charge), cooled, and packaged for later use. Immediately prior to laminating, the veneer was reheated in a tunnel (roller) veneer dryer. The suitability of this technique was confirmed by earlier tests comparing the mechanical properties of southern pine and Douglas-fir as manufactured by the conventional Press-Lam process and by this modification.

The veneer was press dried as two separate groups because of the difference in green moisture contents: Heartwood (30-35 pct), sapwood (140 pct). The sapwood was press dried twice as long as the heartwood (11 min vs 5.5 min at 360° F, 50 psi). These press drying times were chosen to produce veneer having an average moisture content of about 15 percent. Using this modified drying-laminating procedure, one must take note of the drying or moisture loss which will occur in the veneer during the reheating step. The veneers were reheated in a roller dryer at 290° F for 4 minutes. Moisture loss on reheating was about 3.5 percent. The target moisture content was 10 to 12 percent. Spot checks of production averaged 11.4 percent.

The press drying, reheating, and laminating resulted in a thickness loss in the Douglas-fir veneer of about 6 percent. There was also a small but significant loss of 2 percent in width of the veneer during the processing.

The red oak veneer used to fabricate the posts and rails was press dried and reheated in the same manner as the Douglas-fir. Green veneer moisture content was about 85 percent. The press drying (14 min, 360° F, 50 psi) and reheating (4 min, 300° F) resulted in a laminated product of 11 to 12 percent moisture content. The thickness loss was about 10 percent.

### Yield Calculations and Comparisons

Product yields for Press-Lam were calculated and compared with theoretical yields for lumber sawn by the Best Opening Face (BOF) method (15) (table 3). Because most logs are slightly elliptical in cross section and are also tapered, four measurements were needed to characterize bolt dimensions. The maximum and minimum diameters of all of the 151 Douglas-fir bolts cut were measured at both the top and bottom ends. All of the recovered veneer was counted and identified for each bolt. The dimensions of the green veneer were known. The dry volume was calculated (Appendix A) from the dressed dimension board size. In the laboratory operation, no attempt was made to maximize yield during cutting, e.g., by stitching veneers or by including wane and pitch pockets.

The most direct comparison of BOF and Press-Lam yields was obtained[3] by assuming that the same size product could be made—i.e., 1½ by 4½-inch dry dressed dimension of sawn material of varying lengths. This material could then be used to fabricate a glulam beam—the same size as the bridge stringers. From log dimensions as input, the BOF computer program assumes the log to be a truncated cone. Volumes were calculated by the Smalian formula (average top and bottom area times length). The sawn boards are of varying lengths. The same program was also used to calculate a stud recovery from an assumed 8-foot-long, 9-inch-diameter veneer core. The estimated recoveries for BOF and Press-Lam were about equal, both green and dry (table 3). The overall increased cubic volume yield for Press-Lam, 10 percent green and 13 percent dry, was in the assumed core stud recovery.

Most likely, the BOF yields are higher (5 to 15 pct) than those found in the majority of operating sawmills. Harpole (10) has made estimates of saw yield versus Press-Lam yield for an economic analysis, but Press-Lam yields therein were estimated from commercial veneer operations which may not be immediately applicable to Press-Lam manufacture.

Addressing peeling efficiency only, a theoretical green yield of veneer from the 151 bolts (based upon annulus volume and log volume) is 85 percent with a 9.5-inch core. The actual recovery based upon the above total log volume, was measured to be 72 percent. This implies that the efficiency of the peeling, in this instance, was 85 percent.

Table 3.—Calculation of BOF yield compared to actual yield of Press-Lam from same logs

| Conversion technique | Green yield: Volume | Green yield: Total log volume | Green yield: Efficiency of veneer recovery | Dry yield dressed: Volume | Dry yield dressed: Total log volume |
|---|---|---|---|---|---|
| | Ft³ | Pct | Pct | Ft³ | Pct |
| Best Opening | | | | | |
| Face (BOF) | 1,540 | 74 | | 1,155 | 55 |
| Press-Lam | | | | | |
| Veneer | 1,525 | 72 | 85 | [illegible] | 55 |
| Core | 170 | 8 | | 140 | [illegible] |
| Total | 1,695 | 80 | | [illegible] | 62 |

See Appendix A for calculations.

Assuming conversion of 9.5-in. core to sawn dimension stock using BOF techniques.

## Laminating

### Assembly of Four-Ply Dimension Material

Before laminating, the veneer was cut square to 48-inch lengths and was reheated for 4 minutes at 290° F in staggered sets of four pieces in a veneer dryer. As the veneer pieces came from the dryer, the adhesive was applied (11) and they were assembled stepwise into 1½- by 20-inch dimension boards (fig. 1). Immediately after assembly, the veneers and the filler caul (fabricated of veneers or plywood laminated as a step) were inserted into the 2- by 8-foot press and pressure was applied. The filler caul gaged the spacing of the butt joints between veneers and transmitted pressure to the overlap area of the joints. The pressure applied during laminating was 150 psi and was maintained for about 4 minutes.

[3] [illegible]

As soon as pressure was applied, the next set of four veneers was started through the dryer. Shortly before these emerged from the dryer, the press was opened, the filler caul was removed, and the laminated section slid forward 4 feet in preparation for the addition of the next set of four veneers. This process, which took a total of 6 minutes, was repeated throughout the fabrication of the dimension boards. Each time 21 feet of dimension material extended beyond the outfeed end of the press, it was cut off at a butt joint.

The adhesive used in the laminating was a commercially available, room temperature curing, phenol-resorcinol, extended 8 percent by weight with methanol. The extender lengthened the pot life, decreased the adhesive viscosity, and lengthened the assembly time. The adhesive was applied with an extruder-type spreader. The desired spread rate was 60 to 65 pounds per thousand square feet (lb/1,000 ft²) of glueline.

The desired glueline temperature at the time of pressure application was 190° to 200° F. Boards were produced end to end continuously. Since it was necessary to begin a new day with a cold adhesive joint, production was stopped each day at the beginning of the next board. The initial built-up step was reheated each morning in an oven before the next day's lamination began.

The fabrication strategy for dimension boards (1½ x 20 in.) was to ignore any randomization methodology. In other words, the boards were manufactured in an assembly line manner. Thus, most often, veneers from the same log and bolt were in sequence through the board, and thereafter from board to board. Also, the order of the boards was not changed in the manufacture of bridge stringers. Of all the veneer produced, 96.5 percent was used to fabricate dimension boards. Some boards fall out of order for one reason or another, but this was due to avoidance of an undesirable board property (warp, narrowness, etc.).

### Quality Control and Related Tests on Dimension Material

During the manufacture of the components for the Press-Lam bridge, the laminating operation was closely monitored. Adhesive spread rates and glueline temperatures were periodically checked and adjusted to maintain acceptable levels. After assembly, samples were removed from each day's production and adhesive bond quality was checked.

The acceptable levels of performance were as follows:

1. Glueline temperature 190° to 200° F.
2. Adhesive spread rate of 60 to 65 lb/1,000 ft².
3. Eighty percent or more wood failure on 1-inch-diameter cores tested in shear.
4. Maximum of 5 percent delamination on end-grain gluelines after three-cycle accelerated aging exposure.

**Glueline Temperature.**—The temperature was measured by inserting a thermocouple between the third and fourth plies at the time a set was assembled. The temperature of subsequent gluelines could be adjusted by changing the temperature in the next reheating operation. Once the temperature readings stabilized in the desired range, the temperatures were checked only periodically.

**Adhesive Spread Rates.**—The spread rate of the adhesive was checked and adjusted after each new batch of adhesive was added to the spreader and again about 1 hour later. In addition, a random check of spread rate was made at least once and sometimes twice a day. If values were outside the targeted range, the spread rate was adjusted accordingly.

The average spread rate was 62.9 lb/1,000 ft² with a standard deviation of 3.21 lb/1,000 ft². The range was 51.3 to 78.1 lb/1,000 ft². This actual range exceeded the targeted range but the quality control tests discussed later (2, 25) did not identify any inferior adhesive bonds. Because of these positive test results, the dimension boards were accepted as quality material.

**Shear Tests.**—Bond quality was checked using glueline shear tests on 1-inch-diameter cores. The test was patterned after procedures developed by Selbo (25). The cores tested in this case were about 1 inch in diameter, 1.5 inches long, and contained three gluelines. Three cores were taken from each day's production sample. The criterion for acceptance was the percentage of wood failure obtained. Of the 36 random daily samples tested the wood failure averaged 93 percent. Only one sample (at 78 pct) was below the targeted 80 percent average wood failure value. All subsequent samples indicated acceptable levels of wood failure so no adjustments were made in the gluing procedure. Load at failure was observed to be quite variable but not a controlling factor. It averaged 920 psi (Coefficient of Variation (COV) = 26 pct) in a range of 670 to 1,340 psi.

**Delamination Tests.**—The three-cycle vacuum pressure soak and dry exposure test (2) was also used to check bond quality. All 108 test specimens passed the test with less than 5 percent delamination.

## Manufacture of Bridge Components

### Bridge Stringers

The bridge stringers were made at FPL by laminating three pieces of the dimension material together to achieve a 4½- by 20-inch cross section (fig. 2). Before laminating, all of the dimension material was surfaced on two sides with an abrasive planer, to a thickness of about 1.5 inches. The three pieces of dimension material to be used in any one stringer were then laid up dry and the boards were arranged to eliminate coincidence of butt joints in adjacent boards.

The stringers were laminated two at a time in a 4- by 20-foot hydraulic press. The adhesive and the application equipment were the same as were used in fabricating the dimension boards. The total assembly time was 30 to 35 minutes, and pressure was maintained at 200 psi for 16 to 20 hours at or above 70° F.

### Deck Panels

Deck panels were fabricated for two testing series and for installation in the bridge itself. All the panels were made with the 1½- by 20-inch- by 21-foot Press-Lam dimension material ripped to slightly larger than the final thickness of the deck panel. Panels for Test Series 1 (table 4) were manufactured at FPL. Panels for Test Series 2 (table 4) were

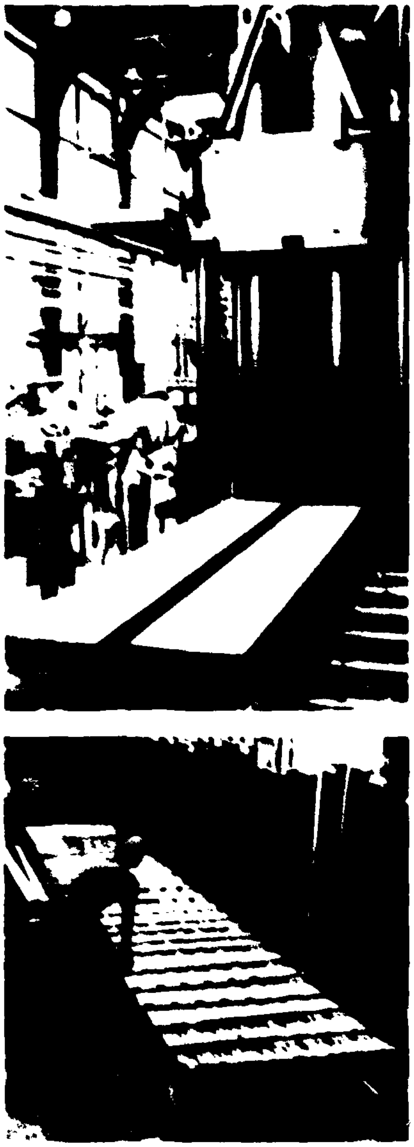

*Figure 2.—Lamination of Press-Lam dimension stock (upper) into bridge stringers, and (lower) into bridge deck panels.*
(M 147 [illegible]) (M 147 [illegible])

*Figure 3.—Press-Lam components being removed from the treating cylinder.* (M 145 [illegible])

manufactured in a commercial glulam manufacturing facility. The bridge deck panels (27 ft 4 in. long x 4 ft or 3 ft 2 in. wide x 3½ in. deep) were manufactured in a second commercial glulam plant (fig. 2). Series 2 panels and the bridge deck panels were made from finger-jointed laminations, as is commonly done in glulam bridge decks. Voluntary Product Standard PS 56-73 covering structural glulam lumber (32) was followed for Test Series 2 and the final deck assemblies, and a phenol resorcinol adhesive was used for both the finger joints and the face glue joints.

**Guard Rails, Curbs, and Posts**

The red oak guard rails, curbs, and posts for the Press-Lam bridge were manufactured at FPL. The procedure was generally the same as that used for the Douglas-fir stringer manufacture. Individual components were sawn from pieces of laminated red oak dimension stock.

**Preservative Treatment of Components**

After final dimensional and structural checks were made at FPL, all bridge components were transported to a commercial treating facility for creosote preservative treatment. Previous work in treating Coast Douglas-fir Press-Lam at FPL (29) indicated that a modified Rueping process produced a total creosote loading of 11.6 pounds per cubic foot (pcf). This work, coupled with experience in treating red oak Press-Lam railroad ties with creosote (30) and AWPA Standards (5), provided the guidelines for treating the bridge components.

Because of the relatively small size of the total charge, both species were treated in one cylinder (fig. 3). For this treating schedule the initial air pressure of 55 psi was held for 2 hours and maintained while the tank was filled with Grade 1 creosote. The pressure was then raised at a rate of 1 psi per minute until it reached 125 psi. The pressure was held constant and temperature maintained at 200° F for 3 hours. A final vacuum of 26 inches was held for 1 hour. According to treating plant track scales, the charge of 4,946 board feet or 412 cubic feet, picked up a total of 4,020 pounds of creosote, which is equivalent to 9.8 pcf. Table 5 lists the creosote uptake for the more easily weighed, smaller pieces of Douglas-fir and red oak Press-Lam. The smaller pieces of Douglas-fir had uptakes ranging from 7.4 to 16 pcf, whereas the uptake of the red oak ranged from 7.4 to 10.8 pcf. This range in preservative uptake was larger than previously encountered (29).

Inspection of the various components immediately after treatment indicated that the deck panels were very wet with excessive creosote solution, whereas the stringers and smaller Douglas-fir and red oak pieces looked quite dry and clean. As a result of this observation the deck panels were introduced into another treating cylinder on the following day and were subjected to a steaming treatment at 220° F for 3 hours followed by 1 hour at a vacuum of 26 inches. It was later noted that the

Table 4.—Bridge deck description and test results

| Series | Deck construction | Type of test | Load block Size[1] | Load block Position[2] | Maximum load | Deflection under load[3] | Comments |
|---|---|---|---|---|---|---|---|
| | | | In | | Lb | In | |
| 1 | Two panels at 7 ft long x 30 in. wide x 6¾ in. thick, tested on 6 ft span, deck laminations longitudinal | Stiffness | 15 x 20 | on | 25 000 | 0.20 | |
| | | | line load | — | 40 000 | .30 | |
| | | | line load | — | 40 000 | .30 | |
| | | | 15 x 20 | off | 25 000 | .30 | |
| | | Strength | 15 x 20 | off | 79 000 | .80 | Shear failure 6.6 x design load[4] |
| 2 | Two panels at 8½ ft long x 8 ft wide x 3½ in. thick, tested on 8 ft span, spiked transversely to 14 in. deep stringers spaced 2 ft apart | Stiffness | 10 x 20 | on | 50 000 | .67 | |
| | | | | off | 50 000 | .62 | |
| | | | | off | 40 000 | .59 | |
| | | | 10 x 10 | on | 25 000 | .50 | |
| | | | | on | 30 000 | .62 | |
| | | Strength | 12 x 12 | on | 58 000 | .78 | Failed at 4.2 x design load |
| | | | 10 x 10 | off | 45 000 | .58 | Failed at 3.7 x design load |
| | | | | off | 47 000 | .64 | Failed at 4.0 x design load |
| | | | 10 x 20 | on | 74 000 | .83 | Failed at 6.2 x design load |
| | | | 15 x 20 | on | 79 000 | .68 | Failed at 6.6 x design load |

[1]Small dimension in direction of traffic flow on bridge. Line load applied over a 1½ in. wide block.
[2]Load block placed at midspan on the dowel joint (on), adjacent to the dowel joint (off), or parallel to the supports as a line load at midspan (—).
[3]For strength tests, last measured load prior to failure.
[4]Design wheel load = 12,000 lb.

Table 5.—Treating results on Press-Lam bridge components less than 8 feet long

| Material | Dimensions | Creosote uptake Average | Creosote uptake Range |
|---|---|---|---|
| | In | Pct | Pct |
| Douglas-fir | [1]1½ x 4½ x 96 | 12.7 | 9.9-16.0 |
| | 4½ x 20 x 25½ | 10.6 | 9.8-11.2 |
| | 4½ x 20 x 11¾ | 10.2 | 7.4-14.8 |
| Red oak | 4 x 8 x 8 | 10.8 | 10.1-10.8 |
| | 4 x 8 x 36 | 8.6 | 7.7-9.8 |
| | 8 x 8 x 51½ | 7.9 | 7.4-8.4 |

[1]Test specimens used to evaluate effect of preservative treatment on bending strength properties.

steaming treatment caused each deck panel to expand 1 to 2 inches in width, or about 3 percent.

Inspection of the treated material did not reveal any serious problems. A very slight amount of collapse was observed in two of the deck panels and some raised grain was evident. Some of the lathe checks in the deck panels were noted to line up in such a fashion as to promote a few through checks; however, none of these exceeded 6 inches in length. The preservative treatment in general was considered acceptable.

## Bridge Design and Component Testing

### Preliminary Bridge Design

Previous work at FPL (23) suggested that large Press-Lam timbers made from low-quality Douglas-fir logs could be assigned an allowable bending stress of approximately 1,500 psi. The Douglas-fir logs used in this study were of significantly higher quality, and 2,000 psi was chosen as a best estimate of their allowable bending stress.

The AASHTO Specifications for Highway Bridges were used for all phases of the design (1). The AASHTO calculations for bending and shear stresses in the stringers are straightforward, and the load distribution factors were deemed appropriate. However, the design equations for the deck did not appear to be directly applicable to this design. Reasons for discrepancies between the generalized equations and the design requirements of this bridge configuration will be discussed later.

Based on the design equations of the AASHTO Specifications for an HS-20 load rating, the preliminary design stringer spacing for 4½- by 20-inch stringers was calculated to be 24 inches. The preliminary design deck thickness, based on AASHTO bending moment requirements and previous

Forest Service experience with short-span bridge design, was chosen to be 3⅛ inches. Steel dowels ⅞ inch in diameter and spaced 10 inches apart were selected to connect adjacent deck sections.

The design details of the secondary structural material (i.e., curbs, rails, and posts) were supplied by the Virginia Department of Highways and Transportation.

**Bridge Component Test Program**

Allowable stresses to be used in the final bridge design were determined by a test program. As this was to be a prototype structure, there was no prior service record on which to base any engineering judgments needed in the design. The goal of the test program was to define the material properties accurately enough to ensure that the bridge would be structurally safe, and that a minimum amount of material was used in the final design.

**Stringer Tests.**—Longitudinal stringers must resist loads primarily in bending. Thus, the design stresses for the stringers were established by a series of destructive bending tests.

Eighteen randomly selected stringers were two-point loaded in edgewise bending to failure in accordance with ASTM D 198 (3) (fig. 4). Load points were placed 4 feet apart and were symmetric about midspan. Load and midspan deflection were continuously monitored during the tests. Typical failure involved a butt joint in one of the outer plies.

The average modulus of rupture for these 18 tests was 5,450 psi with a COV of 9 percent (fig. 5). The average modulus of elasticity for all 36 stringers was 1.71 million psi with a COV of 7 percent (fig. 6). Based on these tests and additional tests on treated material, an allowable bending stress of 2,000 psi was derived (Appendix B).

In addition to the aforementioned destructive tests, the remaining 18 stringers were proofloaded in bending to ensure their structural adequacy. The proofloading of wood members in bending is not recommended for all applications. Freas (8) determined that some failures of wood ladders in the 1940's were due to minute compression failures probably induced during a proofload. Lewis et al. (16) studied the

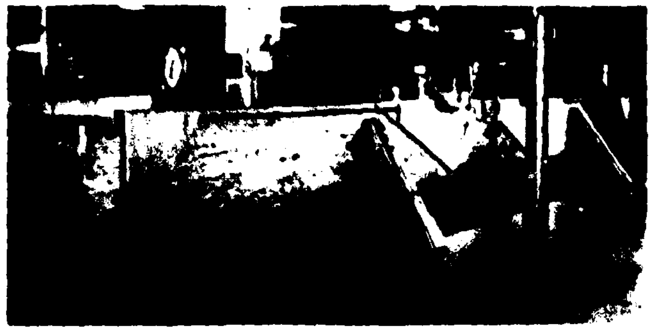

*Figure 4.—Bending tests conducted on Press-Lam bridge stringers.* (M 144 [illegible])

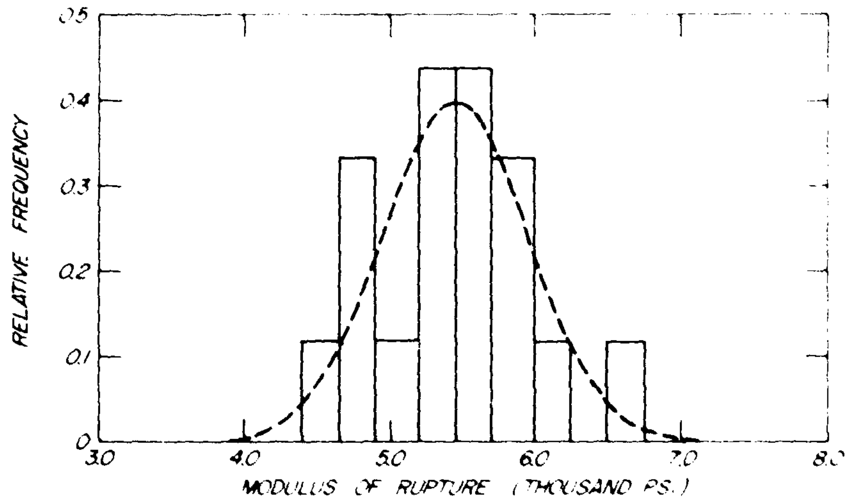


*Figure 5.—Histogram of modulus of rupture data and assumed normal distribution for 18 bridge stringers.* (M 146 940)

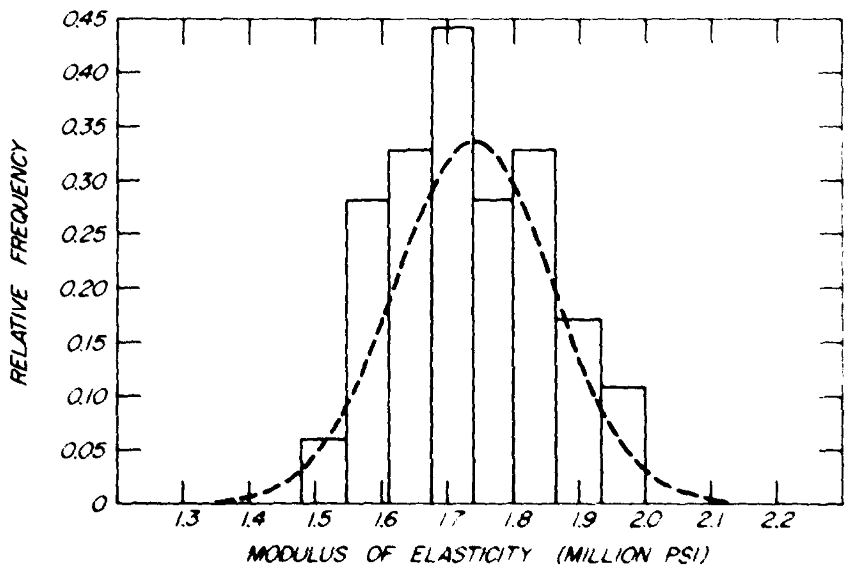


*Figure 6.—Histogram of modulus of elasticity data and assumed normal distribution for 36 bridge stringers.* (M 146 941)

U.S. Forest Products Laboratory.

Design, fabrication, testing, and installation of a Press-Lam bridge, by J. A. Youngquist, D. S. Gromala, R. W. Jokerst, R. C. Moody, and J. L. Tschernitz. Madison, Wis., FPL, 1979.
20 p. (USDA For. Ser. Res. Pap. FPL 332.)

A prototype highway bridge of Press-Lam, a PLV product, was erected in Virginia. It was field tested to its AASHTO HS-20 design load. Preliminary allowable stresses were determined by data from destructive laboratory tests on 18 full-scale stringers and 6 sections of decking made from Douglas-fir. All bridge components were treated with creosote to an average retention of 9.8 pcf.

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effects of induced compression failures on the strength of box beams. They concluded that preexisting compression failures in these members can cause a marked reduction in both tensile strength and toughness. For these reasons, indiscriminate use of prooflloading on members of unknown strength or end use orientation has never been and is not now recommended.

The Press-Lam bridge stringers were proofloaded under laboratory conditions to a predetermined stress level of 3,800 psi. This proofloading providing a final quality control check on the manufacturing process. The members were installed on the bridge in the same orientation in which they were proofloaded. Data collected during proofloading was used as an indication of which stringers would be most suitable for installation in the bridge. A summary of reliability-based calculations was made regarding the proofload level and selection criteria of the 12 stringers to be treated and shipped to the bridge site (Appendix C). Actually, only 11, which were randomly selected from these 12, were required for bridge construction.

**Deck Tests.**—The design equations for laminated timber bridge decks in the AASHTO Specifications (1) are based on theoretical analyses of a partially loaded infinite strip of a thin, orthotropic plate. These equations, and the test results used to verify them, were originally presented by McCutcheon and Tuomi (18). However, the equations are not applicable to designs which violate the assumptions of thin plate analysis. For this design the stringer spacing was so narrow that a double truck tire print would essentially span the full gap between stringers while inducing little bending stress in the deck.

Although many closed-form mathematical solutions exist for orthotropic plates (28), none were considered to accurately model this particular bridge deck. For this reason, two series of tests were conducted to establish the load-carrying capacity and deflection characteristics of the deck under a simulated wheel load (table 4).

In each test series the load was applied in 5,000-pound increments. A

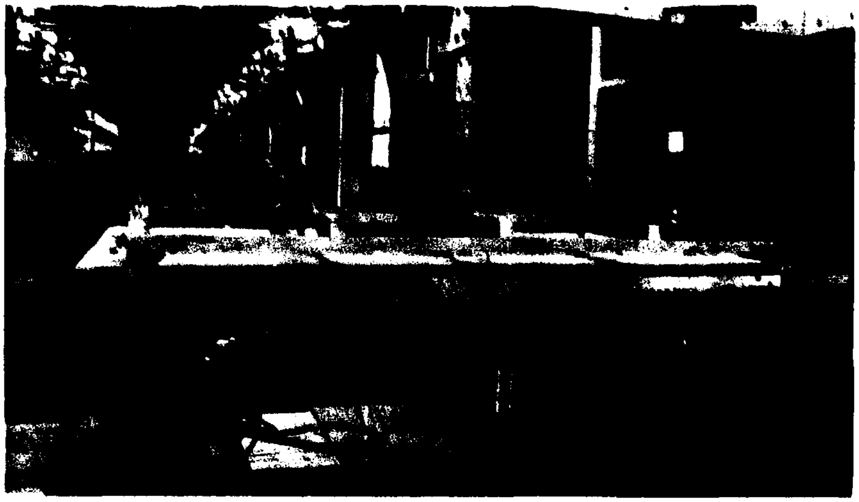

*Figure 7.—Series 1 test setup for 6¾-inch thick Press-Lam bridge deck on a 6 foot span. (M 144 109-8)*

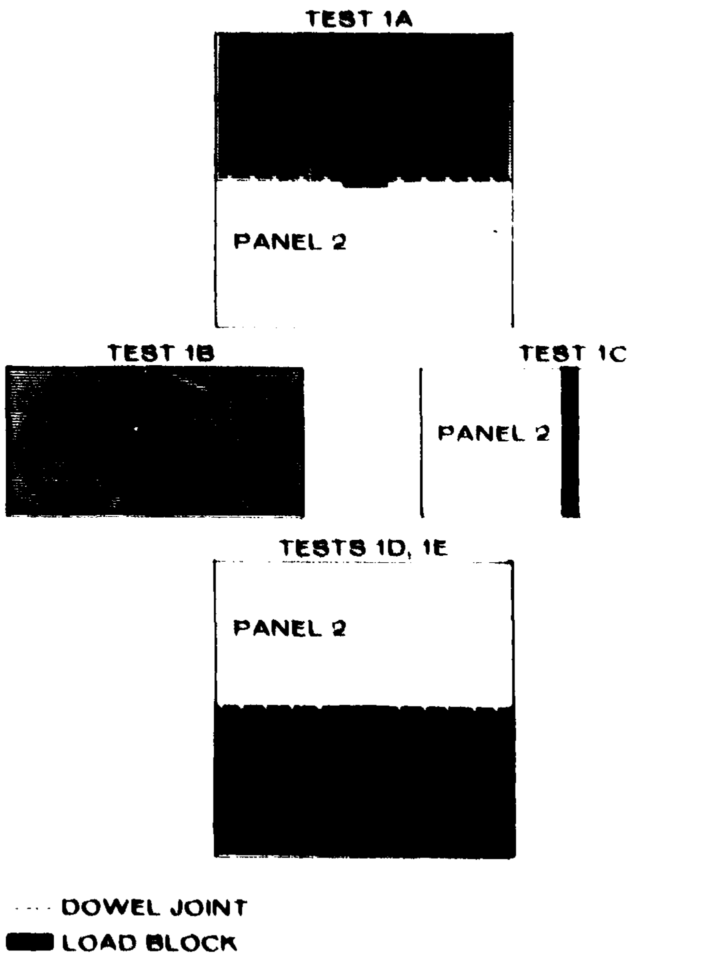


*Figure 8.—Deck panel configurations for Series 1 tests. (M 148 101)*

hand-operated pump was used to increase the load gradually over a 1-minute interval. The load was then held constant for approximately 30 seconds to allow for electronic scanning and recording of all data channels prior to the next load increment. This procedure was repeated until the deck panels failed.

In Test Series 1, two 6¼-inch-thick deck panels were joined together and center-loaded on a 6-foot span (figs. 7 and 8). This span/depth ratio was chosen to examine the plate bending properties of Press-Lam. The first four tests in Series 1 were conducted to evaluate the elastic response of the Press-Lam. The final test in the series was conducted to failure. When loaded to failure, this panel withstood primary bending stresses of about 5,300 psi before failing in rolling and horizontal shear (fig. 9).

Because the actual bridge configuration was not modeled in Test Series 1, Series 2 was conducted to examine the deck/stringer system as it would exist in the bridge itself. Two pairs of 3⅛-inch-thick deck panels were manufactured for Series 2. For each test, a pair of these deck panels were dowel-connected and spiked to five stringers. The stringers were spaced 2 feet apart and spanned 8 feet (figs. 10 and 11). A 14-inch stringer depth was chosen with the 8-foot span in order to approximate the flexibility of the stringers in the actual bridge installation.

Ten tests were conducted to examine such factors as dowel-joint rigidity, load distribution, and deflection characteristics, and the effect of load-block size on failure mode (table 4).

As expected, the modes of failure for this series were markedly different from the rolling and horizontal shear failure exhibited on the 6-foot span. Deck failures were of a "punching" type (fig.12) when a small load block was used, while stringers failed in bending (fig. 13) when a standard double-tire print load was applied.

Maximum failure loads ranged from 3.7 to 6.6 times the HS-20 design wheel load. The deck materials were at about 12 percent moisture content at test, and because the deck system was designed for use at a moisture content greater than 16 percent, a wet-use factor of 80 percent was applied (19). This reduced the expected range of maximum failure loads to about 3.0 to 5.3 times design load. Even with this reduction, the deck thickness of 3⅛ inches was considered adequate.

Deflection of this system under load was largely as anticipated. The dowels provided excellent load transfer with minimal differential displacement between panels (fig. 14).

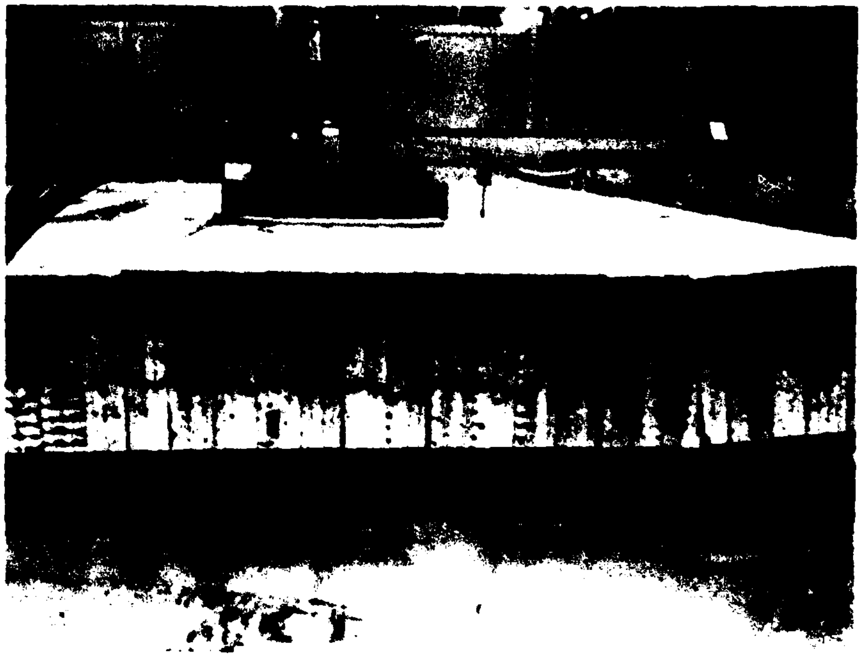

*Figure 9.—Failure of Series 1 test deck in rolling shear (right), followed by horizontal shear (center).* (M 144 109-11)

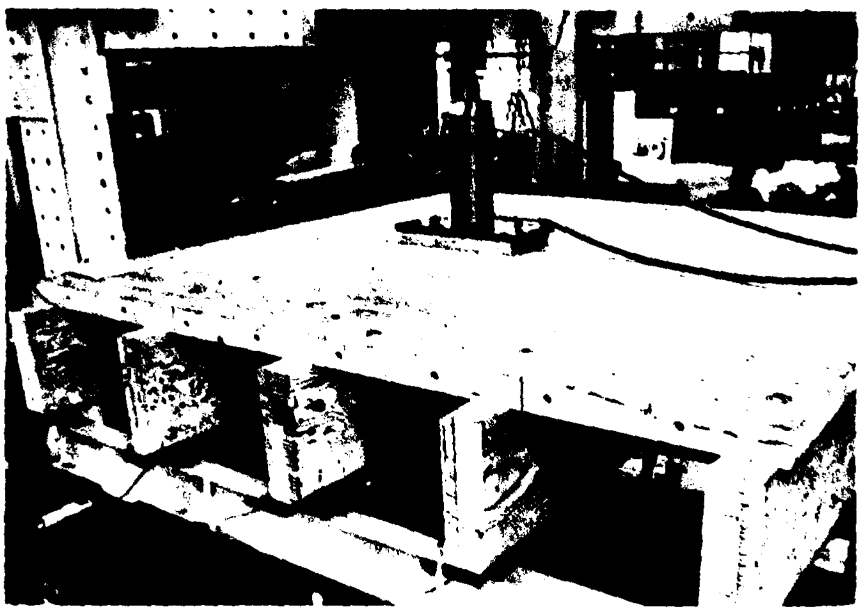

*Figure 10.—Series 2 test setup for 3⅛-inch-thick Press-Lam bridge deck attached to stringers 2 feet apart on an 8-foot span.* (M 144 450-2)

**Other Tests.**—In addition to the testing of primary structural components, two other factors important to bridge performance were examined—spike withdrawal resistance

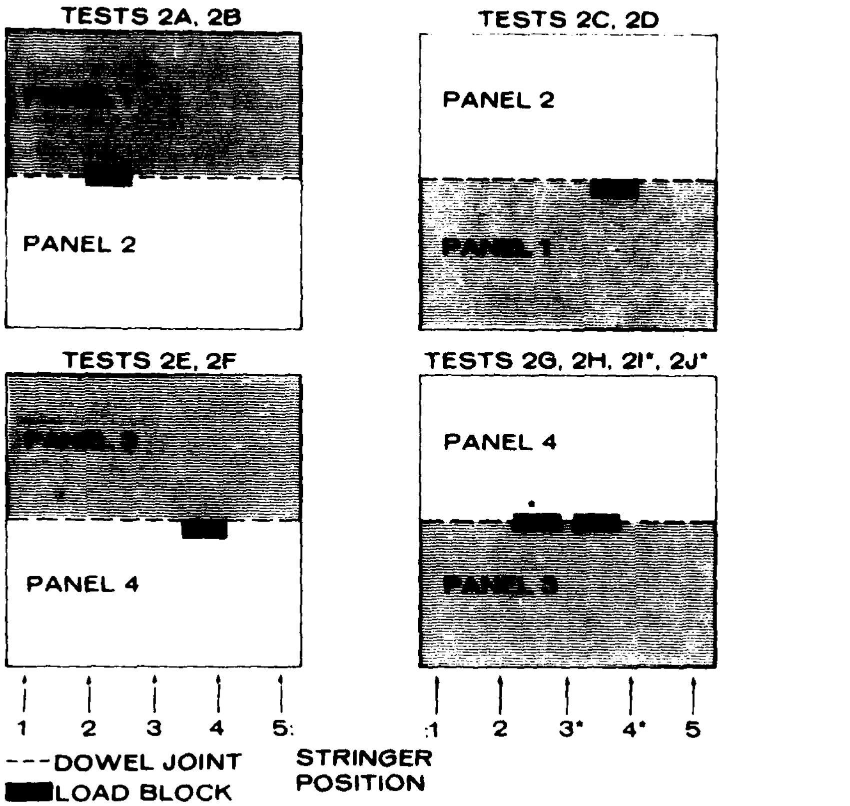


*Figure 11.—Deck panel configurations for Series 2 tests. Only stringers 3 and 4 were damaged in tests 2G and 2H. These stringers were replaced and two additional tests were performed (2I, 2J) with panels in the same configuration.* (M 148 102)

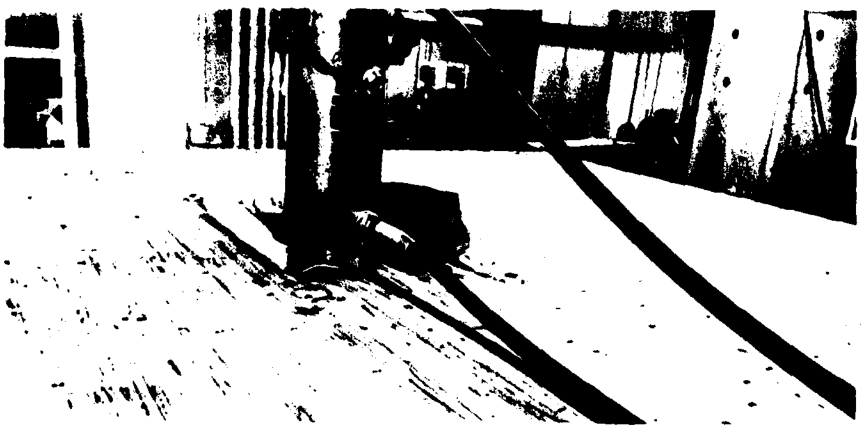

*Figure 12.—Failure of Series 2 Press-Lam test deck in "punching" shear.* (M 144 450-2A)

and the effects of preservative treatment on bending properties.

Spike withdrawl properties of Press-Lam were assessed in a limited study. In 10 tests, the withdrawal resistance of Press-Lam averaged 70 percent of the resistance of glulam. Withdrawal loads of spikes driven directly into butt joints were not significantly lower than the others. Based on these tests, no problem was anticipated in maintaining a tight deck/stringer interface.

Forty specimens of Douglas-fir Press-Lam (1½ x 4½ in. x 8 ft) were tested to evaluate the effects of creosote treatment on bending strength and stiffness. Results of these tests indicate a significant reduction in both stiffness (4 to 12 pct reduction, 80 pct confidence) and strength (7 to 19 pct, 80 pct confidence) due to treatment. These reductions are more likely due to the conditions of treatment rather than the chemicals used (31). The magnitude of the stiffness reduction is comparable to the 0 to 10 percent range predicted by Luxford and MacLean (17). However, the reduction in bending strength is slightly less than the 15 to 25 percent range cited by the same authors.

Because larger members would not reach high internal temperatures as quickly as these smaller members, the magnitude of the strength reduction for the large members was believed to be less. Thus, using this limited data, the allowable bending strength determined from the stringer tests was reduced by 10 percent (Appendix B) for in-use application.

**Final Bridge Design**

Based on the results of the structural component testing, coupled with the design methods outlined in the AASHTO Specifications (1), a final bridge design was proposed by FPL. Using the design allowable bending stress of 2,000 psi from Appendix B, and the applicable AASHTO load distribution factor, the stringer spacing was widened from the 24-inch preliminary design spacing to a 30-inch final design stringer spacing. To offset the resulting increase in deck stresses, the final thickness of the deck was increased from the preliminary design thickness of 3⅛ to 3½ inches. Preliminary design estimates of spike and dowel size and spacing appeared to be satisfactory. The final design (fig. 15) was submitted to and approved by bridge designers at VDH&T.

## Installation and Evaluation

**Installation**

The VDH&T installed the Press-Lam bridge structure as part of a bridge replacement and widening project on State Secondary Route 610, in the George Washington National Forest, 100 miles west of Washington, D.C., near Orkney Springs in Shenandoah County, Va.

A five-man bridge crew from the VDH&T replaced the existing

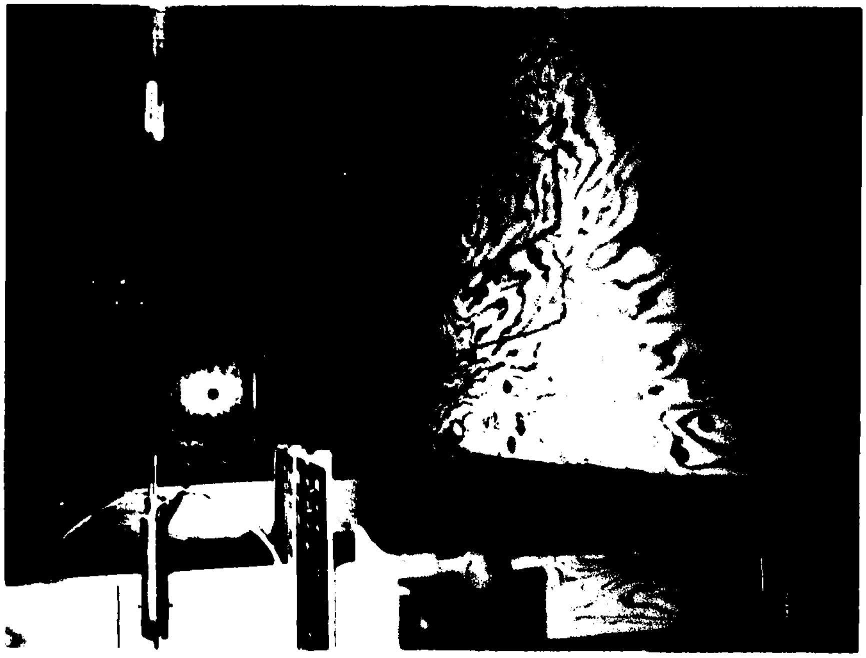

*Figure 13.—Failure of Press-Lam stringer in bending in Series 2 test.* (M 144 502-4)

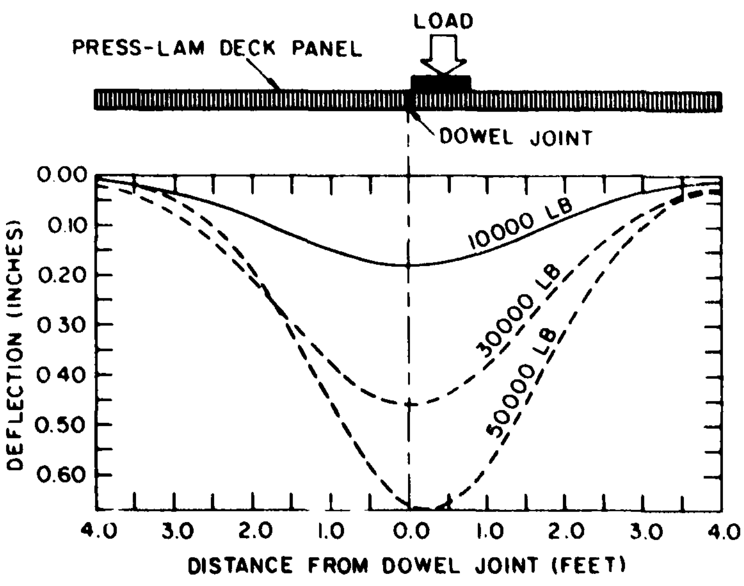


*Figure 14.—Deflection profiles across dowel joint at three load levels.* (M 146 615)

substandard one-lane steel stringer-timber deck bridge with the experimental two-lane Press-Lam bridge superstructure in about 4 work days beginning April 18, 1977 (figs. 16 and 17). The labor and equipment used for the installation, has been compiled by Sprinkel (26) (table 6). The construction rate of 2.7 ft² per hour for the 5-man crew and 5.0 ft² per equipment-hour compares favorably with other bridges of similar size (26). The two-lane bridge spans 18 feet 6 inches and is 26 feet wide from curb to curb. Eleven stringers, 20 inches deep by 4½ inches wide by 18 feet 4 inches long were used. A total of five 3¼-inch-thick deck panels were used, three of them measuring 48 inches wide and two of them measuring 38 inches wide.

The Press-Lam bridge was assembled quickly with only minor delays and inconveniences.

1. The deck panels increased in width after steaming following treatment. This difficulty required one bridge abutment to be modified slightly.

2. The last panel was difficult to jack into place because the jack could not be positioned between the backwall and the panel. A crane was used to support the jacks as the last panel was positioned.

3. Creosote leaking from the Press-Lam members caused undesirable working conditions.

Although 4 days were required to install the Press-Lam structure, the road was closed to traffic for only 1 work day. With experience, the bridge crew could probably construct a Press-Lam bridge somewhat faster than reported here.

**In-Place Evaluation of Completed Structure**

On May 4, 1977, a truck loaded to the HS-20 design load level was used to load test the Press-Lam bridge (fig. 18). Scale measurements indicated that each pair of wheels on the tandem rear axle produced a load of about 10,200 pounds. A taut wire and scale were used on each stringer to measure midspan deflections for different loading positions. Stringer deflections were slightly less than anticipated, indicating that the AASHTO wheel load distribution factor is somewhat conservative. A dial gage was used to measure the deflections of the center deck panel midway between selected stringers for selected loading positions. Relative panel deflections were small for each of the positions measured, indicating that the steel dowels provided satisfactory load transfer between panels. A detailed report summarizing the entire proofloading test series has been prepared by Sprinkel (26).

Estimates of the type and number of vehicles using the bridge are being made with traffic counting equipment at selected times and from observations of the number and type of vehicles using the bridge during each site inspection. Data were collected for several hours during the first day the bridge was load

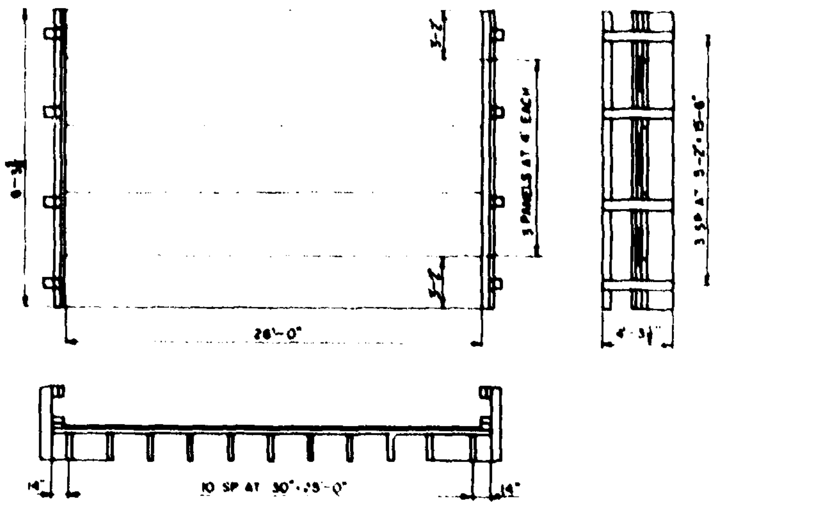

*Figure 15.—Construction schematic of Press-Lam bridge over Stony Creek, Va.* (M 145 646)

**Table 6.—Labor and equipment required to install Press-Lam bridge (26)**

| Activity | Labor: Hours | Labor: Number of workers | Labor: Worker hours | Equipment: Type | Equipment: Number of hours |
|---|---|---|---|---|---|
| Moving Press-Lam members and crane to bridge site | 8 | 5 | 40 | 1 Bridge truck | 8 |
| | | | | 1 Crane | 8 |
| Erecting Press-Lam stringers and deck panels[1] | 16 | 6 | 96 | 1 Bridge truck | 16 |
| | | | | 1 Crane | 16 |
| | | | | 1 Pickup truck | 16 |
| | | | | 1 Boom truck | 16 |
| Attaching Press-Lam rails and posts and general cleanup | 8 | 5 | 40 | 1 Bridge truck | 8 |
| | | | | 1 Crane | 8 |
| Totals | 32 | | 176 | | 96 |

[1] Includes approximately 1 hour for removal of existing steel stringer timber deck superstructure. The hardware had been removed from the existing superstructure while the substructure was being widened.

**Table 7.—Bridge traffic loading data (25)**

| Date | Number of hours | Number of vehicles: < 10,000 pounds | Number of vehicles: > 10,000 pounds | Number of vehicles: Total | Number of vehicles: Per hour |
|---|---|---|---|---|---|
| 4-18-77 | 4 | 0 | 14 | 14 | 3.5 |
| 5-03-77 | 3 | 2 | 15 | 17 | 5.7 |
| 5-04-77 | 7 | 3 | 18 | 21 | 3.0 |
| 6-01-02-77 | 24 | | | 121 | 5.0 |

tested and inspected, and for a 24-hour period on June 1-2, 1977 (table 7).

To get an indication of the number of large loads and overloads, mechanical strain recording gages were installed at midspan on the bottom side of four bridge stringers.

### Long-Term Bridge Performance Evaluation

The performance of the Press-Lam bridge superstructure will be monitored over a 5-year period by the Virginia Highway and Transportation Research Council. This study will:

1. Evaluate the behavior of the bridge subjected to a test load similar to HS-20.
2. Monitor dimensional changes and relative movements of the stringers and deck panels. Attention will be focused on gluelines, butt joints, and relative deck and stringer displacements.
3. Monitor the moisture content of the stringers and deck panels. Attention will be focused on the condition of the wearing surface, drainage, and superstructure areas where water might collect.
4. Estimate the type and number of vehicles using the structure over a 5-year period.

Data on all four items were collected during the prooftoading tests conducted on May 4, 1977 and in May 1978, and will be taken at the end of 5 years. Data on items 2, 3, and 4 were also collected 3, 6, and 24 months after installation.

## Summary

### Project Description

The concept of parallel laminating veneer into thick sheets of any width or length has been examined as an alternative to solid-sawn timber or glulam for structural-size members. The Press-Lam process, developed at the Forest Products Laboratory (FPL), uses a veneer lathe to cut the wood, a hot press to dry it, and glue and another press to reassemble the hot, dry veneer sheets into finished structural members. Press-Lam advantages include increased yields of lumber from logs, more uniform engineerng properties of finished products, and improved penetration and retention of oil-based preservatives. A highway bridge, manufactured entirely from parallel laminated veneer, was constructed to

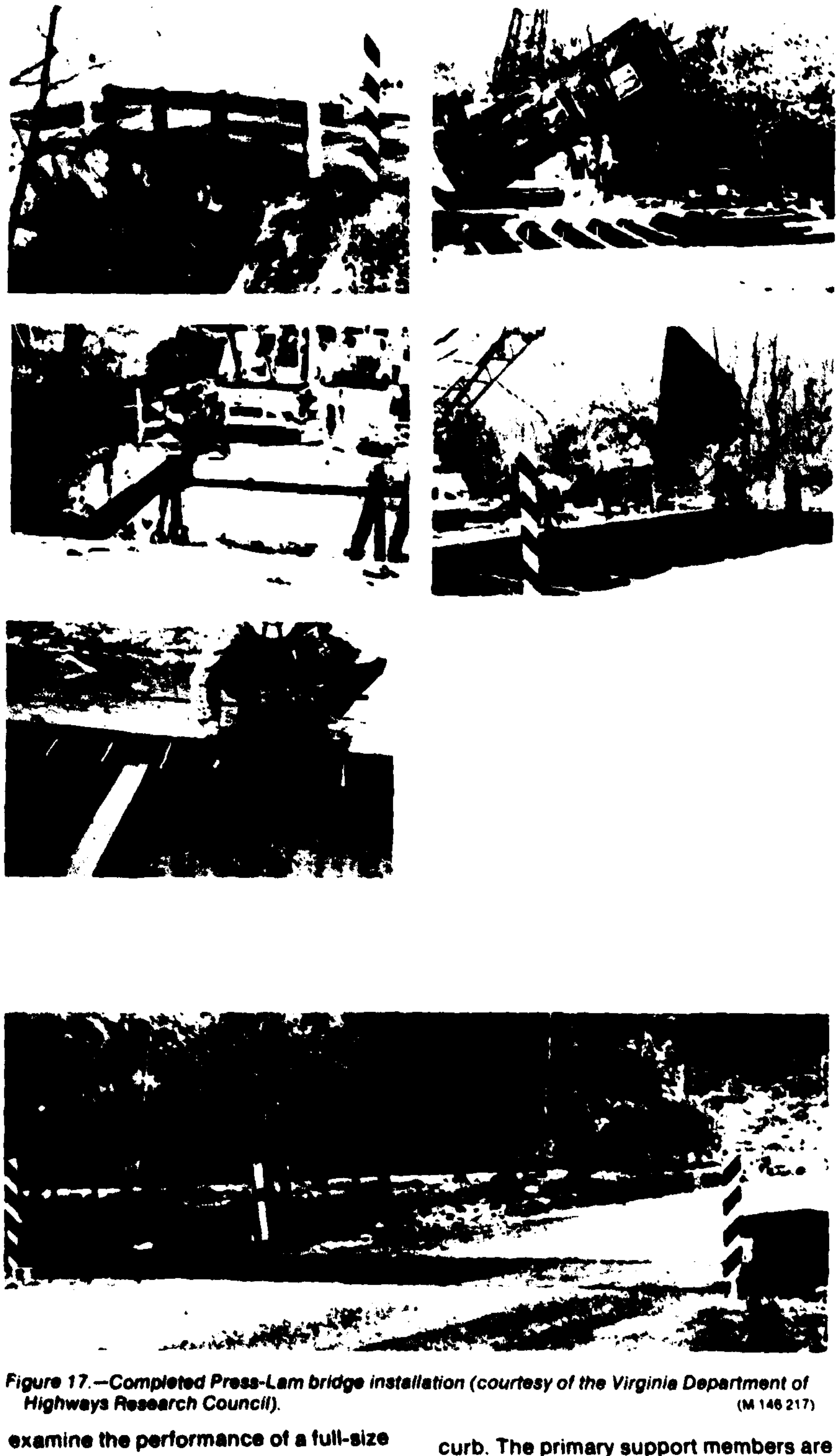

*Figure 17.—Completed Press-Lam bridge installation (courtesy of the Virginia Department of Highways Research Council).* (M 146 217)

examine the performance of a full-size Press-Lam structure.

**Bridge**

The two-lane bridge spans 18 feet 6 inches and is 26 feet wide from curb to curb. The primary support members are eleven longitudinal stringers, 20 inches deep by 4½ inches wide by 18 feet 4 inches long. The transverse deck panels are 3½ inches thick and 27 feet 4 inches long; the three interior panels are 4 feet wide and the two approach panels are 38 inches wide. The stringers and deck panels are made from Douglas-fir. The guardrails, posts, and curbs are made from red oak logs.

All bridge components are treated with creosote to an average retention of 9.8 pcf.

The bridge stringers were designed according to AASHTO specifications. The bridge deck design was based on previous research and component testing at FPL.

The bridge over Stony Creek, located on Virginia State Secondary Route 610, in the George Washington National Forest, 100 miles west of Washington, D.C., was installed without difficulty. Traffic was interrupted for a total of 7 hours.

A 1-inch-thick bituminous wearing surface was applied to the surface of the Press-Lam bridge approximately 6 months after the bridge was erected. This bituminous surface is permeable and therefore serves as a wearing surface but not as a moisture barrier.

**Bridge Test Program**

At FPL, 18 stringers were tested and six deck configurations were tested to failure. The 18 stringers resisted loads from 2.3 to 3.1 times the value selected for design. The deck panels, tested with a simulated wheel loading, all resisted at least 3.7 times the HS-20 design load.

Approximately 2 weeks after construction, the bridge was load-tested with a truck having a tandem rear axle weight of 41,000 pounds. This truck produced stresses equivalent to the standard AASHTO HS-20 loading. Observed deflections under the proofload were within acceptable limits.

The Virginia Highway and Transportation Research Council will be overseeing a 5-year bridge performance evaluation program.

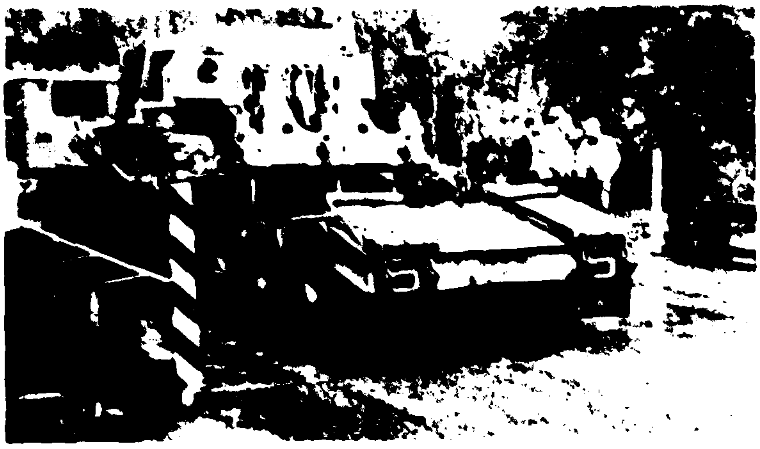

*Figure 18 —Loaded rear tandem axle trailer used for load testing Press-Lam bridge (courtesy of the Virginia Department of Highways Research Council).* (M 146 216)

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# APPENDIX A

## Calculation of Volume Yield

Potential volume yields were calculated for material for bridge stringers derived from these 23 logs by the Press-Lam process, and compared with calculated yields if the same logs were sawn by the Best Opening Face (BOF) method Total log volume was assumed to be best characterized in terms of the average log area (top and bottom) and log length

Number of logs 23
Number of bolts (for peeling) 151
Total log length

BOF 644 ft

Press-Lam 654 ft

$$\text{Average log diameter } 24.4 \text{ in} \left(\text{From Av log area} = \frac{\Sigma \text{ Smalian log volume}}{\Sigma \text{ Log length}}\right)$$

$$\text{Total log volume} = \pi\left(\frac{\text{av dia}}{2}\right)^2 \cdot \text{total log length}$$

$$\text{BOF} = \pi\left(\frac{24.4}{2}\right)^2 (644\ \text{ft}) \cdot \frac{1}{144}\ \frac{\text{ft}^2}{\text{in}^2} = 2{,}091\ \text{ft}^3$$

$$\text{Press-Lam} = \pi\left(\frac{24.4\ \text{in}}{2}\right)^2 (654\ \text{ft}) \cdot \frac{1}{144}\ \frac{\text{ft}^2}{\text{in}^2} = 2{,}124\ \text{ft}^3$$

Green

**Press-Lam**

Veneer

Size: 21.5 x 0.420 x 52 in. (0.272 $ft^3$)

Number: 5,617

Volume: 0.272 $ft^3$ x 5,617 = 1,526 $ft^3$

Core

Size: 9.5 x 52 in.

Number: 151

For BOF calculations, assume core diameter = 9.0 in. and

bolt length = 8 ft

Core yield: 2 2x3's: 1.689 x 2.72 (green dimensions)

5 2x4's: 1.689 x 3.75 (green dimensions)

Yield per 8-ft core: 2.27 $ft^3$

Total core yield: 2.27 $ft^3$ x 75 8-ft cores = 170 $ft^3$

Total volume = 1,526 + 170 = 1,696 $ft^3$

**Press-Lam Veneer Recovery Factor**

An estimate of the peeling efficiency can be made by comparing the volume of veneer recovered with the volume of the annulus between the outer diameter and the core diameter:

Annulus total volume = total log lenth (log area − core area).

$$\text{Log area} = \pi\left(\frac{24.4}{2}\right)^2 \frac{1}{144} = 3.25\ \text{ft}^2$$

$$\text{Core area} = \pi\left(\frac{9.5}{2}\right)^2 \frac{1}{144} = 0.49\ \text{ft}^2$$

Annulus total volume = 654 (3.25−0.49) = 1,805 $ft^3$

Volume of green Press-Lam veneer = 1,526 $ft^3$

$$\text{Efficiency of veneer recovery} = \frac{1{,}526}{1{,}805} \times 100 = 84.5\ \text{percent}$$

**BOF Dimension**

Size: 1.714 x 5.248 (green dimension)

Average recovery per log = 67 $ft^3$

Total volume = 67 $ft^3$ x 23 logs = 1,541 $ft^3$

**Dry Dressed**

**Press-Lam**

Dimension boards

Size (4-ply board): 20 x 1.5 in. x 21 ft (4.375 $ft^3$)

Number: 258

| | |
|---|---|
| Volume: 258 x 4.375 $ft^3$ = | 1,129 $ft^3$ |
| Moisture-shear sections = | 7 $ft^3$ |
| Unused veneer[1] = | 34 $ft^3$ |
| | 1,170 $ft^3$ |

[1]In addition to these dimension boards, some material was used for other research purposes. In a production facility, this material could have been converted into finished product.

Core

Dry volume/green volume = volume loss factor:[2]

2 x 3: (1.5 x 2.5)/(1.689 x 2.72) = 0.82
2 x 4: (1.5 x 3.5)/(1.689 x 3.75) = 0.82

Net volume = green volume x volume loss factor:

170 x 0.82 = 139 $ft^3$
Total volume = 1170 + 139 = 1,309 $ft^3$

**BOF Dimension**

Dry volume/green volume = volume loss factor:[2]
(1.5 x 4.5)/(1.714 x 5.248) = 0.75
Total volume = 1,541 x 0.75 = 1,156 $ft^3$

[2]More shrinkage in BOF material (0.75) than in Press-Lam dimension boards (0.82) was due to lower moisture content needed for lamination.

# APPENDIX B

## Methods Used to Derive Allowable Bending Stresses for Stringers

The principles used to adjust lumber test data to allowable design properties are those presented in ASTM D 2915 (4). The lower fifth percentile of the distribution was estimated, and reduction factors were applied to account for load duration and protection against overload. A factor to account for preservative treatment was also applied.

As proofloading was to be used to assure the design levels, it was not believed necessary to calculate tolerance limits. Rather, a point estimate of the fifth percentile was made by standard statistical methods (20). The data were assumed to be normally distributed and the fifth percentile was calculated as "t" standard deviations below the mean. For 18 data points (17 degrees of freedom), t = 1.740. Using the mean of 5,455 psi, the standard deviation of 503 psi, and letting NM designate the near minimum of distribution,

$$NM = 5{,}455 - (1.74 \times 503)$$
$$= 4{,}580 \text{ psi}$$

The following factors then convert the near-minimum strength into the allowable stress:

Load duration and accidental overload: 0.475
Preservative treatment factor = 1/1.1

Thus, a design level of 4,580 x 0.475 x 1/1.1 = 1,980 or about 2,000 psi was determined.

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U.S. GOVERNMENT PRINTING OFFICE: 1979-651-111/29

# APPENDIX C

## Summary of Reliability-Based Calculations Regarding Proof Load Level and Stringer Selection Criteria

### Prooflcading of Bridge Stringers

The 18 bridge stringers remaining after the test program outlined previously were proofloaded in bending to check for manufacturing defects and to assure structural integrity. Previous testing of large Press-Lam members made from low-grade logs indicated that an approximate design stress of 1,500 psi could be used (9). Although strength variability is quite low for sound Press-Lam timbers, one specimen in this test program failed at a load 28 percent lower than the rest. This specimen was later shown to contain a defective glueline. The proofload level was chosen to maximize the chance of identifying members with such defects while minimizing the chances of damaging beams that withstood the proofload.

### Literature

A recent study at Washington State University (27) examined the effects of proofloading on end-jointed lumber. Results showed no significant reduction in strength of end-jointed Douglas-fir specimens that had been proofloaded in bending to 90 percent of their expected ultimate strength.

Kisser and Steininger (12) tested small, clear specimens of three species and found microscopic slip planes (which precede the onset of small compression failures) at 60 percent of ultimate strength, and visible failures at 80 percent of ultimate strength.

Based on these studies, it was assumed that the onset of compression failures (the cause of "damage" during proofloading) could occur at a range of bending stresses from as low as 60 percent of ultimate stress (small, clear specimens) to higher than 90 percent (end-jointed dimension lumber).

### Proofload Level

For the purpose of this study, a proofload level of 3,800 psi or 70 percent of the average expected ultimate stress (83 percent of the estimated near-minimum ultimate stress) was selected as a level that would minimize the possibility of damage and maximize the likelihood of detecting defective material.

As only 12 of the 18 stringers were needed for the actual bridge and all sucessfully resisted the proofload, several criteria were used in an attempt to select the 12 strongest:

1. Impressions of performance under load (audible cracks, discontinuous load-deflection curve, etc.) were considered. Any evidence of abnormal behavior caused the specimen to be rejected.

2. The remaining stringers were used in order of decreasing modulus of elasticity. The good correlation between strength and stiffness in Press-Lam has been shown with smaller specimens. This phenomenon suggests that stiffness could be used as a criterion for selection.

### Damage Considerations

Statistical methods were then used, based on a set of assumptions, to determine the probability that any of the 12 "acceptable" stringers were damaged during proofloading.

Several assumptions were made regarding the shape of the data distribution, the fraction of ultimate load that would induce damage, and the effectiveness of stringer selection criteria. In this analysis, the data were assumed to be normally distributed. Damage threshold levels examined were either 80 percent or 85 percent of the expected ultimate load. Two levels of selection effectiveness were assumed: First, perfect selection (theorizing that the six rejected stringers were the six weakest), and secondly, 50 percent effectiveness (assuming that only three of the six weakest were eliminated).

As shown in Table C-1, only the combination of the two conservative assumptions leaves more than a negligible probability of damage in the remaining stringers.

Subject to the conditions noted, the proofload procedure proved to be an effective tool for assuring the structural adequacy of this experimental material.

**Table C-1.—Probabilities that one or more of the 12 stringers used in the bridge were "damaged" by proofloading**

| Effectiveness of selection procedure | Probability of "damage"[1] If $\sigma_D = .80\sigma_{ULT}$ | Probability of "damage"[1] If $\sigma_D = .85\sigma_{ULT}$ |
|---|---|---|
| Pct | | |
| 50 | 0.20 | 0.008 |
| 100 | 006 | 0 |

[1] $\sigma_D$ = stress level at which "damage" occurs.
$\sigma_{ULT}$ = ultimate stress level.